



Tech-X Corporation

Hybrid gas/plasma simulations using DSMC with the VORPAL code

Wen-Lan Wang, Chet Nieter, and Peter Stoltz Tech-X Corp.

Jean-Luc Cambier AFRL/PRSA

ICOPS 2005 18 - 23 June 2005, Monterey, California 32nd IEEE International Conference on Plasma Science

Approved for public release, distribution unlimited.

maintaining the data needed, and including suggestions for reducin	ollection of information is estimated completing and reviewing the colle- g this burden, to Washington Headq ould be aware that notwithstanding OMB control number.	ction of information. Send commen uarters Services, Directorate for Inf	ts regarding this burden estima formation Operations and Repo	te or any other aspect of orts, 1215 Jefferson Day	f this collection of information, vis Highway, Suite 1204, Arlington
1. REPORT DATE MAY 2005	2. DEDODE TYPE			3. DATES COVERED -	
4. TITLE AND SUBTITLE Hybrid Gas/Plasm	g DSMC with the V	ORPAL Code	5a. CONTRACT NUMBER FA8650-04-C-2511		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Wen-Lan Wang;	toltz; Jean-Luc Cai	5d. PROJECT NUMBER OSDB			
			5e. TASK NUMBER R4QP 5f. WORK UNIT NUMBER		
7. PERFORMING ORGAN Tech-X Corp.,562	303	8. PERFORMING ORGANIZATION REPORT NUMBER			
9. SPONSORING/MONITO	AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAI Approved for pub	LABILITY STATEMENT lic release; distribut	tion unlimited			
13. SUPPLEMENTARY NOTES					
dilute (large Knud mixtures using the capabilities. VORI a variety of model the existing PIC m averaging. We pre established DSMC	lsen number) gases. e current plasma sin PAL is a multidiments s for both the plasm	This will allow VO nulation capabilities assional parallel Partia and electromagno onte-Carlo collisions of validation tests e simulations of 1D	RPAL to run hyl s of VORPAL alo ticle-in-Cell plas etic fields. The D n model and addi by comparing V	brid simulationg with the sma simulations SMC simulations the capab	newly added DSMC on code that supports tion model is built on sility to do ensemble ulations with an
15. SUBJECT TERMS					
16. SECURITY CLASSIFIC		17. LIMITATION	18. NUMBER	19a. NAME OF	
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	OF ABSTRACT	OF PAGES 13	RESPONSIBLE PERSON

Report Documentation Page

Form Approved OMB No. 0704-0188



Abstract



We are adding a Direct Simulation Monte Carlo model to the plasma simulations code VORPAL to model dilute (large Knudsen number) gases. This will allow VORPAL to run hybrid simulations of gas/plasma mixtures using the current plasma simulation capabilities of VORPAL along with the newly added DSMC capabilities. VORPAL is a multidimensional, parallel Particle-in-Cell plasma simulation code that supports a variety of models for both the plasma and electromagnetic fields. The DSMC simulation model is built on the existing PIC model by adding a Monte-Carlo collision model and adding the capability to do ensemble averaging. We present here the results of validation tests by comparing VORPAL simulations with an established DSMC code. These include simulations of 1D thermal Couette flow, 1D high speed Couette flow, and 1D heat transfer rate in the transition regime.





VORPAL's capabilities

- Flexible, object-oriented framework supports plasma simulations with electromagnetics, electrostatics, neutral flow, etc.
- Template meta-programming allows a single code base to support simulations of 1,2 or 3 dimensions.
- Overlap of communication and computational result and effective domain decomposition in good parallel scaling.
- Independent numerical libraries for physics processes (e.g. ionization or secondary emission) extend VORPAL capabilites and allow other codes to benefit.





VORPAL's hierarchy

vorpal: simulation and merging excutables

run, merge scripts, vrutils: particle culling, slab extraction vpdata: data analysis and reduction tools

votrol:

domain object, which can contain any of the objects below

vpfluid: fluid implementations (simple and Zalesak FCT)

vpen: EM implementations (Yee, external fields)

vpptcl: particle implementations (Boris, EN, free) vpmsq: messaging implemementations (MPI)

I/0 vpie: implemementations (HDF5)

vpbase:

framework interfaces (particles, fields, EM,

messaging, I/O), datastructures

vpstd: math functions, creator maps, physical constants,

fluid/plasma independent

txmath: parsers, containers, formulas





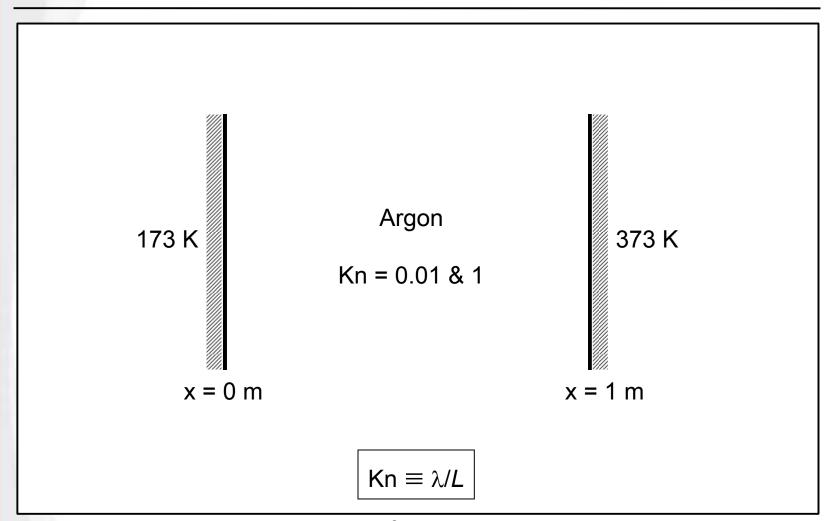
DSMC procedures

- 1. Pushing particles without collisions.
- 2. Performing particle collisions:
 - collision rate: No Time Counter (NTC)
 - collision model: Variable Hard Sphere (VHS)
- 3. Evolving to the steady (equilibrium) state.
- 4. Collecting the ensemble averages.



Simulations of 1-D thermal Couette flow

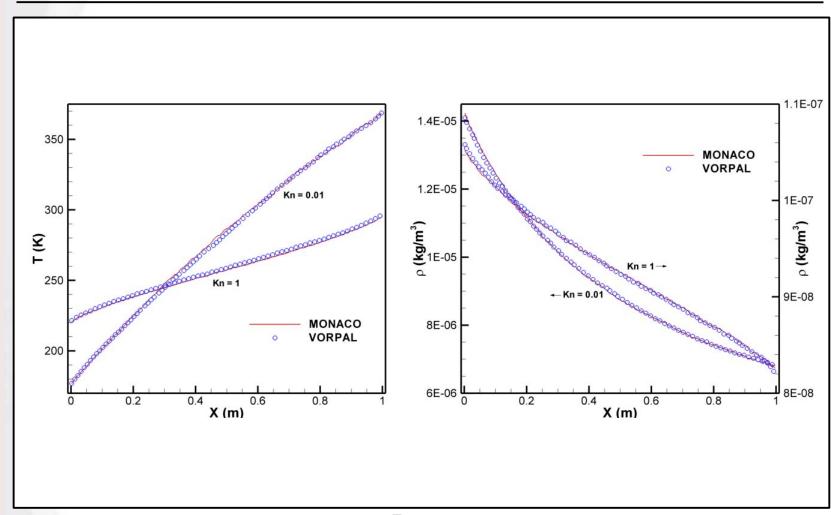






Comparisons of 1-D thermal Couette flow

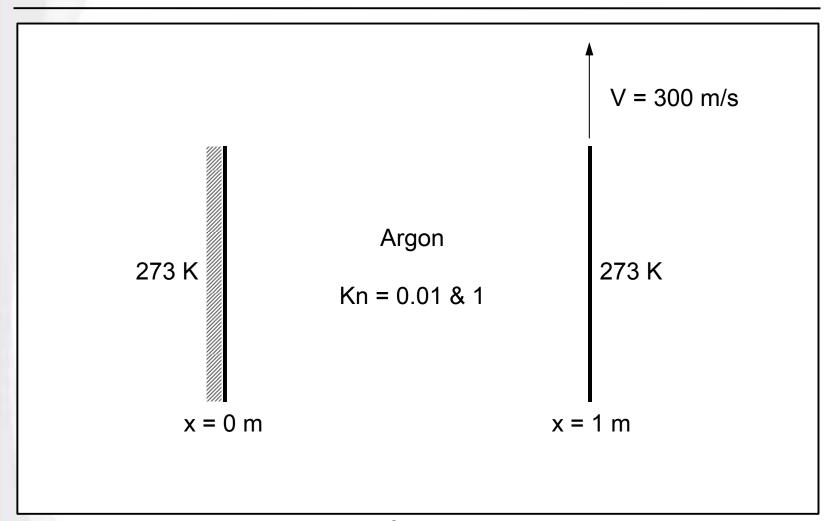






Simulations of 1-D high-speed Couette flow

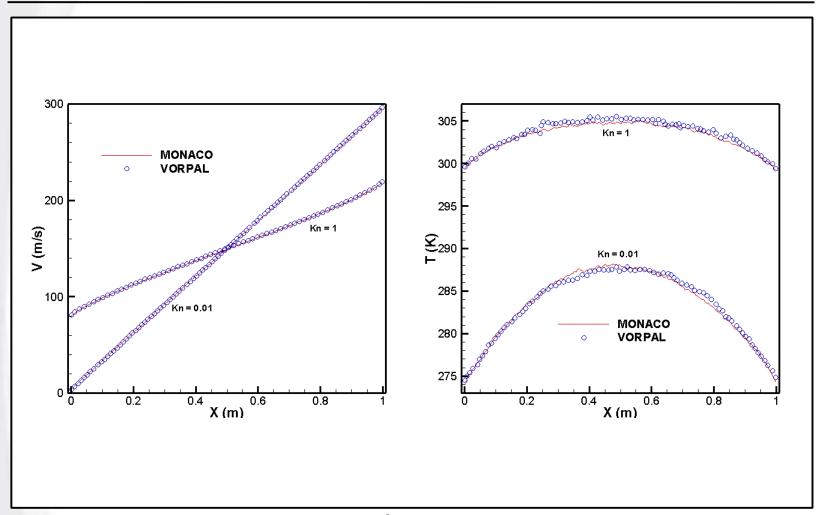






Comparisons of 1-D high-speed Couette flow

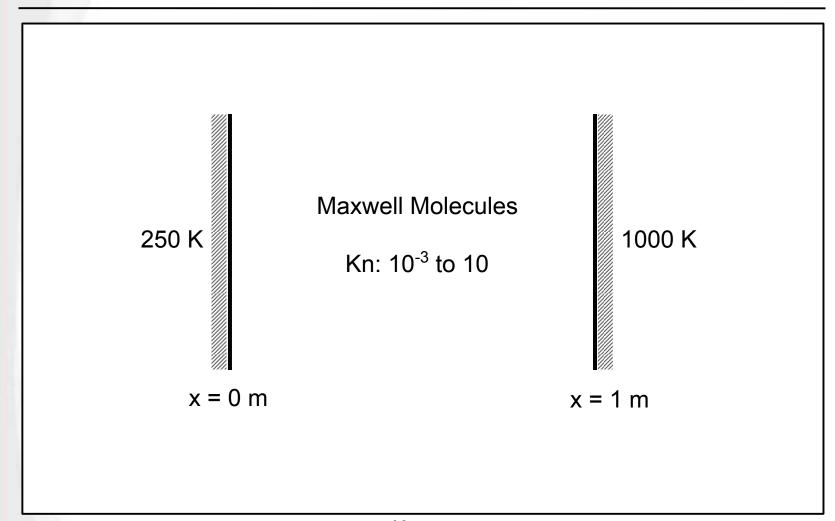






Simulations of heat transfer rate in transition regime

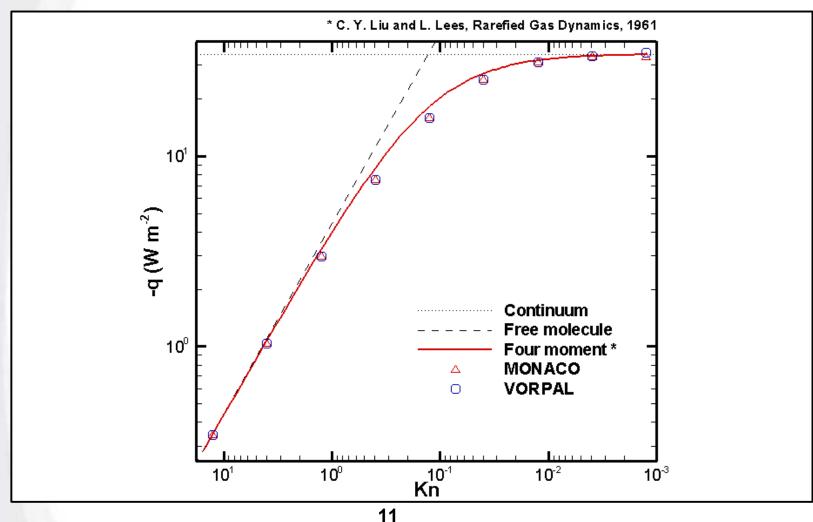






Comparisons of heat transfer rate in transition regime









Summary & Conclusions

- Integration of DSMC capability into VORPAL is proceeding well.
- Added capability will result into a highly capable platform for hybrid gas/plasma simulations.
- Numerical experiments for argon gas at high Knudsen numbers have been conducted.
- Verification & validation is being achieved through excellent agreement with a wellestablished DSMC code.





Future Work

- Performance optimization
- Implementation of internal mode relaxation and chemical reactions
- Continued validation
- Application to selected gas discharges